AN INVESTIGATION OF THE LOADING ON PROBE COUPLED LINES

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THESIS

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on
Probe Coupled Lines

by

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ABSTRACT

If two waveguiding structures support propagating waves with different phase constants, interaction between these waves may be achieved by periodic coupling of the structures. The frequency of interaction depends upon both the periodicity and the loading which results from a particular coupling mechanism.

This thesis presents the results of a study of the loading in a 10 ghz probe coupled, waveguide to coaxial cable periodic coupler.

TABLE OF CONTENTS

LIST OF FIGURES

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I. INTRODUCTION

The coupling between waves with the same phase constant $\beta_1 = \beta_2$ is called uniform, and the theory is well developed, but when $\beta_1 \neq \beta_2$ coupling occurs only when the waves are coupled by periodic functions with period $2\pi/\Delta\beta$ where $\Delta\beta = \beta_2 - \beta_1$. Active coupling of this type was studied by J. B. Knorr [1].

Waveguides and transmission lines loaded at periodic intervals with identical obstacles are referred to as periodic structures. They have characteristics of interest such as the passband-stopband property, which means that there are frequency bands throughout which the wave propagates along the structure separated by frequency bands throughout which the wave is cut off and does not propagate. This is interesting for its frequency filtering aspects. Also occurring in this type of periodic structure is active coupling over a frequency range.

If a coupler is formed by two transmission lines, the phase constants of the traveling waves vary with frequency, as does the difference between phase constants. The period has to be right in order to achieve interaction, and thus no fixed period can provide interaction at all frequencies. It may be possible, however, to achieve broadband interaction by employing the log periodic concepts which have been successfully utilized in antenna design.

The studies of the log periodic structure are based on the assumption that if the variation of the structure period is slow, then any given section of the structure behaves as a periodic structure and at a given frequency, the behavior of waves on this section may be determined by examining the appropriate region of the normalized $\omega - \beta$ diagram.

A prototype for a log periodic structure was built by LT. A. E. Whitehead, [2]. It is shown in Figure 1, and consists of a waveguide periodically coupled to a coaxial cable. The coaxial cable is R G 8/U ($\varepsilon_r = 2.25$) coupled to X-band waveguide (0.4" x 0.9") by a series of 21 probes. The probes were connected to the inner conductor of the coaxial cable and extended 0.125" into the center of the waveguide.

Studying the ω-β curves of the uncoupled lines for a periodicity of 0.618" resulted a crossing at the frequency of 8.75 ghz.

As shown in Ref.[2], an interaction appears at a frequency of 9.45 ghz. This shift may be attributed to the loading of the lines which was caused by the probe coupling technique.

The purpose of this thesis is to investigate the loading effect of the probes used in the coax-waveguide experimental coupler.

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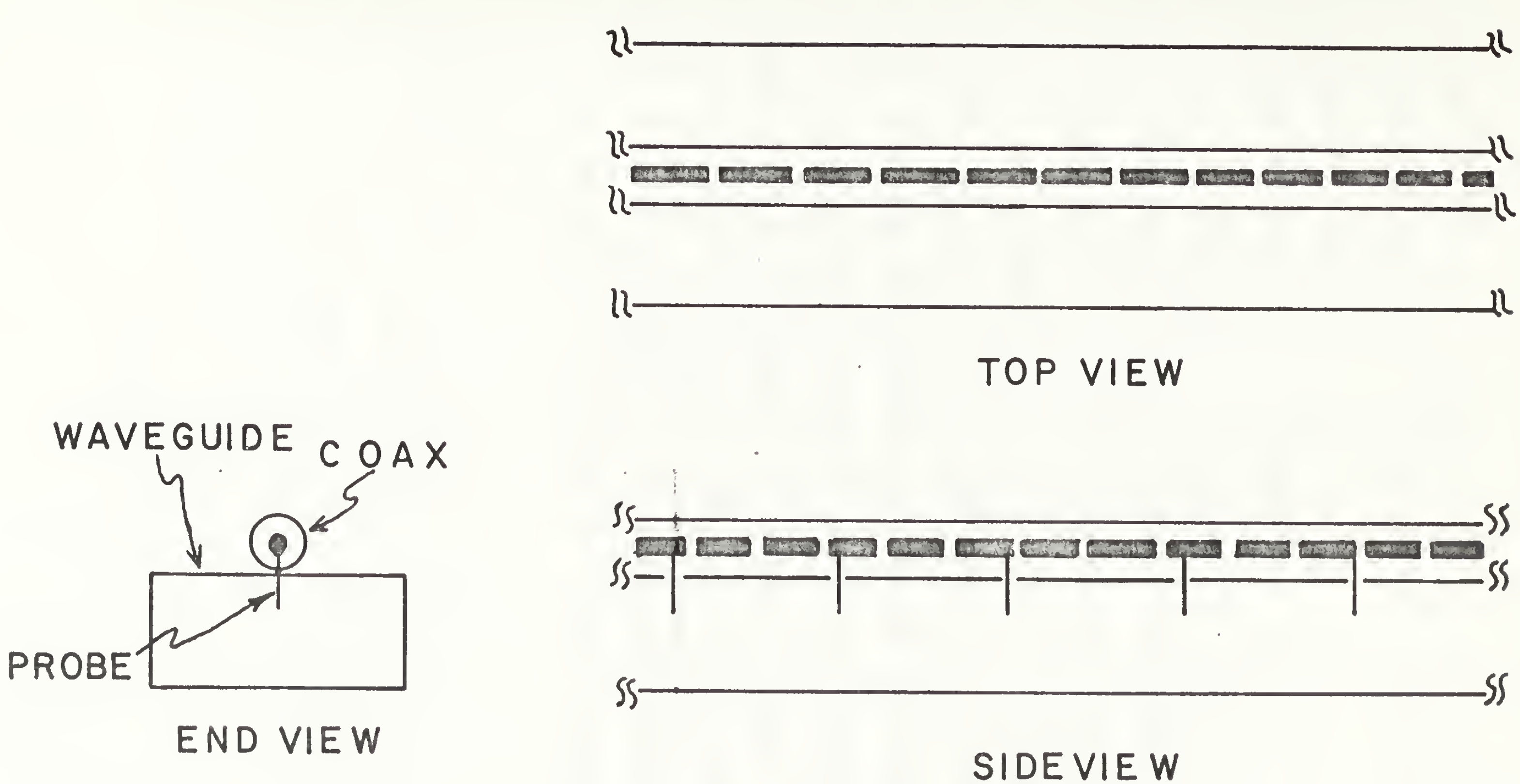

FIGURE I EXPERIMETAL COUPLER

II. THEORETICAL APPROACH

Because there is a shift in frequency due to the load that the probes present to the waves, it is necessary to know what kind of load it is.

A first theoretical approach would be to consider that there are two capacitors, as shown in Figure 2. This is due to the consideration that the probe thickness compares with the thickness of the external conductor of the coaxial cable and the waveguide. As the probe is connected to the inner conductor which has a potential V_1 and the external conductor has the same potential V_2 as the waveguide, a capacitor would appear between these two conductors.

A formula was developed in order to calculate the values of these capacitors. The dielectric was plastic ($\varepsilon_r = 3.4$). Assume that the surface of the external conductor and waveguide is a plane and the probe is a line charge with length L.

Consider first the potential field of two infinite line charges, on the x-z plane parallel to the z axis and at a distance $\pm$ d from this axis. One of these lines is charged with $+\rho_L$ and the other one with $-\rho_L$. The potential of a single line with zero reference at r_o is

$$V = \frac{\rho_L}{2\pi\varepsilon} \ln \frac{r_o}{r} .$$

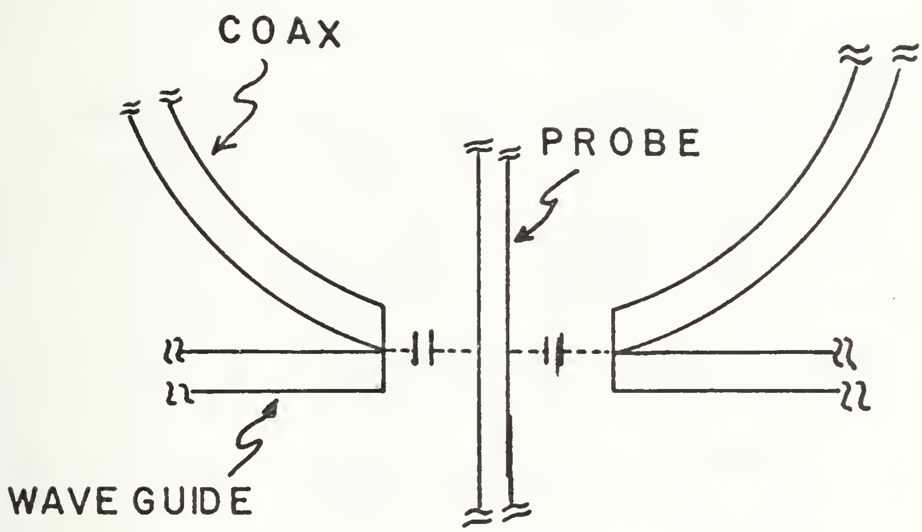

FIGURE 2 CAPACITOR VIEW

The conbined potential field in terms of the radial distance from the positive and negative lines R_1 and R_2, respectively, is

$$V = \frac{\rho_L}{2\pi\varepsilon} \left(\ln \frac{R_{10}}{R_1} - \ln \frac{R_{20}}{R_2}\right) = \frac{\rho_L}{2\pi\varepsilon} \ln \frac{R_{10}R_2}{R_{20}R_1}$$

Placing the zero reference at equal distance from each line, $R_{10} = R_{20}$, and this is equal at the surface $x = 0$, resulting in

$$V = \frac{\rho_L}{2\pi\varepsilon} \ln \frac{R_2}{R_1}$$

Choosing a point on the xy plane and expressing R_1 and R_2 in terms of x and y

$$V = \frac{\rho_L}{4\pi\varepsilon} \ln \frac{(x+d)^2 + y^2}{(x+d)^2 + y^2}$$

$$\ln \frac{(x+d)^2 + y^2}{(x+d)^2 + y^2} = \frac{4\pi\varepsilon V}{\rho_L} \quad \text{and}$$

$$\frac{(x+d)^2 + y^2}{(x+d)^2 + y^2} = k = e^{u\pi\varepsilon V/\rho_L}$$

The equipotential surfaces are those with the same value of V, and if V is constant, K is also constant. For a particular value of $V = V_1$

$$K_1 = \frac{(x+d)^2 + y^2}{(x+d)^2 + y^2}, \text{ and}$$

$$x^2 - 2dx \frac{K_1+1}{K_1-1} + y^2 + a^2 = 0.$$ Completing the squares,

$$\left(x-d \frac{K_1+1}{K_1-1}\right)^2 + y^2 = \left(\frac{2d\sqrt{K_1}}{K_1-1}\right)^2$$

Showing that the equipotential surfaces are cylinders of radius b,

$$b = \frac{2d\sqrt{K_1}}{K_1 - 1}$$

and center

$$y = 0, \qquad x = \frac{d(K_1+1)}{K_1 - 1}$$

The capacitance between a conducting cylinder of radius b and a plane at a distance h from the cylinder, was calculated choosing the conductor as the equipotential surfaces, and the center of these cylindrical surfaces at x = h and y = 0, then solving the equations for the radius and center of the cylinder for d.

$$d = \sqrt{h^2 - b^2}$$

$$\sqrt{K_1} = e^{2\pi\varepsilon V_1/\rho_L} = \frac{h + \sqrt{h^2 - b^2}}{b}$$

$$V_1 = \frac{\rho_L}{2\pi\varepsilon} \ln \frac{h + \sqrt{h^2 - b^2}}{b} \text{, in general}$$

$$V = \frac{\rho_L}{2\pi\varepsilon} \ln \frac{h + \sqrt{h^2 - b^2}}{b} = \frac{\rho_L}{2\pi\varepsilon} \cosh^{-1}\left(\frac{h}{b}\right)$$

but

$$C = \frac{Q}{V} = \frac{2\pi\varepsilon L}{\cosh^{-1}\left(\frac{h}{b}\right)} \qquad \text{farad}$$

Considering that we have two of these capacitors, the total capacitance of the probe will be

$$G = \frac{4\pi\varepsilon L}{\cosh^{-1}\left(\frac{h}{b}\right)}$$

$$\varepsilon = \varepsilon_o \varepsilon_r = 3.4\,\varepsilon_o \qquad\qquad L = 0.22''$$

$h = 0.0235''$

$b = 0.0135''$

Substituting these numbers, the final value for C_t is

$C_t = 0.54\ \rho F$

III. MEASUREMENTS

Two different kinds of data were taken, the first one with the Time Domain Reflectometer, which gave direct indication of the coupling capacitance, and the second one with the Slotted Line in order to calculate the impedance by means of the Smith Chart.

A. TIME DOMAIN REFLECTOMETER (TDR)

This instrument was adjusted for a step output of one volt, as shown in Figure 3, which was the input for all the measurements. The first step was a verification of the velocity of propagation of this step throughout the coaxial cable with a resistance of 50 ohms as a load.

Using the formula from Ref.[3]

$$v_p = \frac{2D}{T} \quad \text{where}$$

D is the distance from the input to the load, known quantity, and T is the time that the wave takes to travel down and back into the cable, as read on the scope of the instrument.

The velocity measured was 1.998×10^8 m/sec which verifies the theoretical value of

$$v_p = \frac{1}{\sqrt{\mu\varepsilon}} = 2 \times 10^8 \text{ m/sec}$$

The coaxial cable has itself an impedance, and it was reflected in a platform or second step, as shown in Figure 4, where the first discontinuity was due to the physical adapter, then next, the step due to the impedance of the coaxial cable

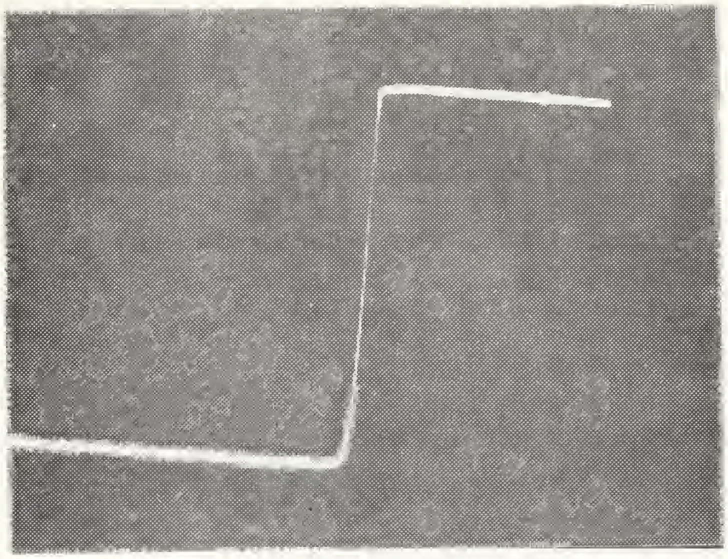

FIGURE 3
TDR INPUT STEP

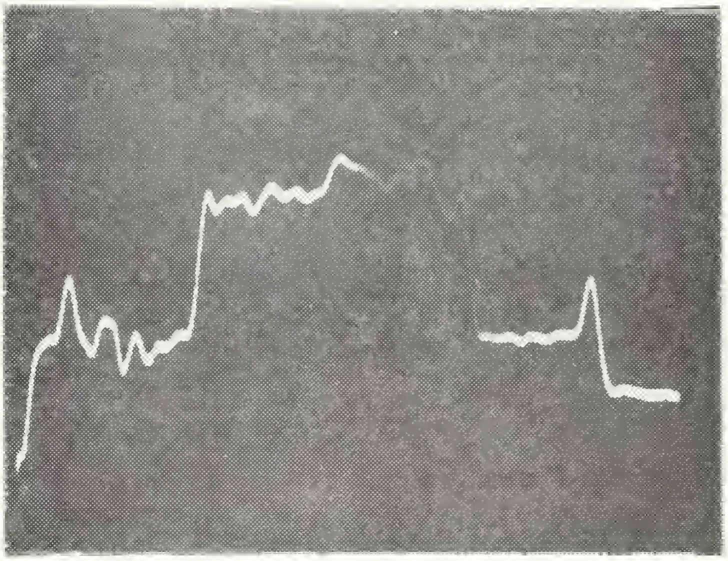

FIGURE 4
COAX IMPEDANCE

appears, and finally, the discontinuity of the 50 ohm coupler.

In order to determine the impedance presented by the probes when the whole structure was coupled, only one of the 21 probes, the nearest to the load, was mounted. Figure 5 shows first the discontinuity of the adapter, then the platform of the coax, the probe effect, and then the second adapter.

Figure 6 was taken with only the probe nearest to the input and the probe nearest to the load in place. The result is the same.

As Ref.[3] indicates, these discontinuities are due to a capacitive effect, and its value can be computed by the formula

$$C = \frac{2}{mZ_o} e_{rmax} \quad \text{farad} \qquad \text{where}$$

$$m = \frac{de_i}{dt}/max \quad \text{volts/sec} \qquad \text{is the slope of the step, and}$$

is read on the scope of the TDR.

Z_o is the characteristic impedance of the coaxial cable, equal to 50Ω, and e_{rmax} is the reading from the platform impedance of the coax to the peak of the discontinuity.

A capacitance was determined for each of the 21 probes. These values were then averaged to arrive at a value of 0.49 pF.

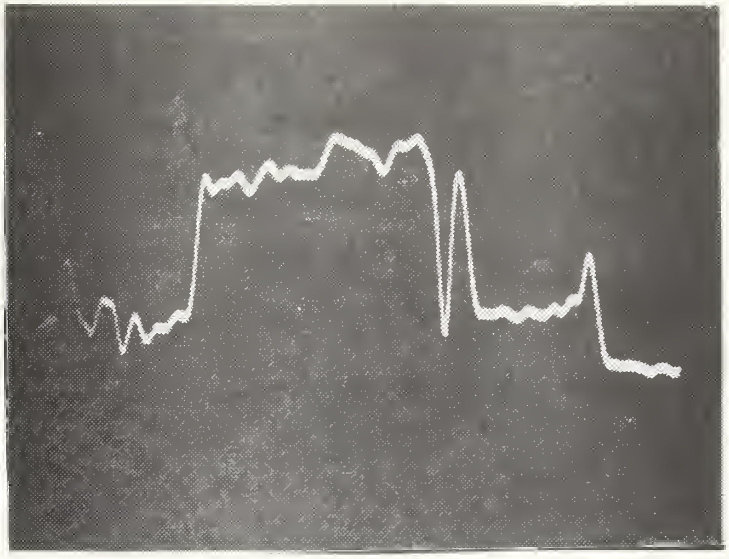

FIGURE 5
RESPONSE OF ONE PROBE

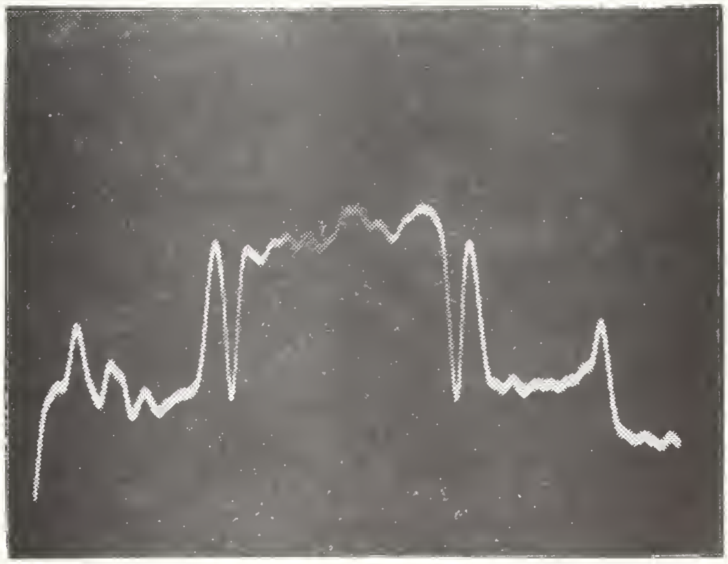

FIGURE 6
RESPONSE OF TWO PROBES

B. SMITH CHART

In order to use the Smith Chart, it is necessary to know the wavelength (λ), the standing waye ratio (SWR), and the distance from a voltage maximum or minimum to the discontinuity or load. The wavelengths were measured with a slotted line. All SWR measurements were made using a Hewlett-Packard square law detector with crystal detector. But a problem arose when the distance from the voltage minimum to the load was taken. A new method was developed in order to solve this problem, and is a combination use of the slotted line and the TDR, and in general can be used when a distance has to be measured. The description of this is as follows: With the wave generator at one frequency, and coupled to the slotted line and structure, the reading of λ and SWR are taken; leaving the slotted line at a position wh-re it reaches a minimum, the wave generator was replaced by the TDR. Then, by means of the formula

$$D = v_p \frac{T}{2} \quad \text{where}$$

v_p is the velocity of propagation of the wavelength through the coax, a known quantity, and Π could be read on the scope of the TDR, the distance between the discontinuities of the slotted line and the probe was calculated with greater accuracy than through a physical measurement.

For 8.5 ghz the data were: $\lambda = 5.8$ cm, SWR = 2.4, and $d_{min} = 0.04\lambda$, which gave a value of the capacitive impedance of 0.51 pF.

Several data were taken at different frequencies, and slightly different values of capacitance were recorded. The variation was between 0.47 and 0.52 pF, and the average value was 0.50 pF.

IV. CONCLUSIONS

All of the measurements were made on different days, and at least ten readings were taken for each one. It is possible to say that the average value of 0.50 pF's for the capacitance of the probes is correct, and furthermore, the experimental values agree with the theory developed.

Besides that, a substantial improvement in the use of the Smith Chart was realized making measurements of distances more accurately, using the slotted line and the TDR.

The value of the capacitive loading contributes to a better understanding of periodic coupling.

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This thesis presents the results of a study of the loading in a 10 ghz probe coupled, waveguide to coaxial cable periodic coupler.

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